Stiffness properties of prosthetic feet under cross-slope conditions

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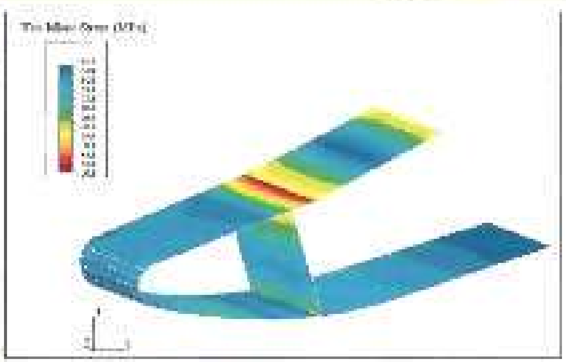
Outline

- Introduction
- Review of Literature
- Rationale
- Hypotheses
- Methods
- Data
- Discussion

Introduction

- Prosthetic feet serve to aid the body in
  - Progression
    - Energy storage and return
  - Weight-bearing stability
    - Durability, compliance
  - Shock absorption
- Recommendation criteria can be influenced
  - Experience
  - Economy
  - Patient knowledge and assertiveness
  - Manufacturer visibility and recommendation

Review



- Clinical Testing:
  - Inconsistent results with relation to foot dependent change - Usually comparing feet to SACH (Hafner, 2002; Van der Linde, 2004; Perry 1997
- Mechanical testing: emphasis on saggital plane
  - Energy Return (Geil, 2002; Zahedi; Van Jaarsveld 1993; Klute 2004; Postema 1997)
  - Fatigue (Hahl, 2000, Meier, Rooyen 1997)
  - Forefoot or heel (Contoyonis, 2001; Ge Postema 1997; Rooyen 1997, Klute, 20
  - Shock absorbtion (Rooyen 1997)
  - ISO 10328, 22675- Fatigue

Review:

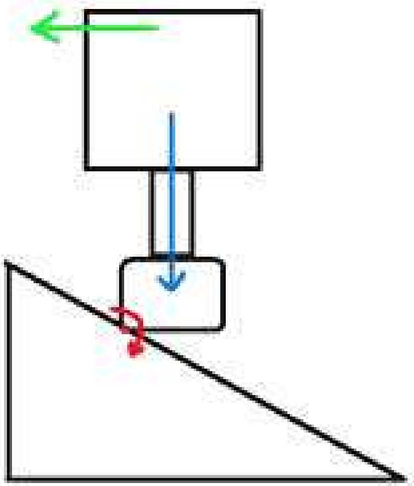
- Rooyen 1997 – Compared characteristics of 2 SACH feet and the effects of fatigue
  - Found significant difference between two SACH feet
- Geil 2000 – Demonstrated that prosthetic feet separate themselves by energy loss/ energy return properties.
- Kabra 1991
  - Measured several characteristics of feet
  - Only article to measure supination/pronation properties.
- Zmitrewicz, 2006
  - Gait analysis of effect of ESAR and Multiaxis functions on gait
  - Found that amputees preferred multiaxis feet and that they may be very useful for older patients

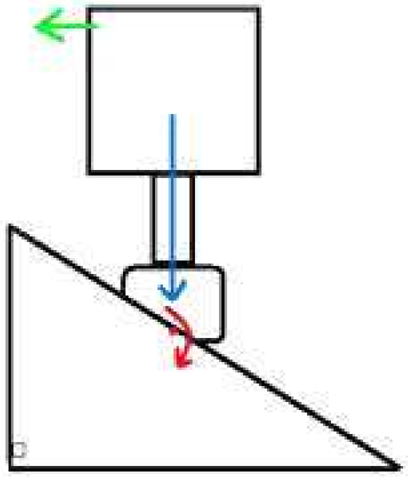
Purpose

- Demonstrate range of compliance in various prosthetic feet at "mid stance" on sloped surfaces
- Illustrate a potential test method for evaluating the coronal plane compliance of prosthetic feet
- Demonstrate the utility of this or similar tests to classify prosthetic feet based on given characteristics

Rationale

- Slope creates point of rotation on one border of foot
- Prosthesis has tendency to rotate about point of contact without force exerted by amputee to maintain erect (proximal brim of socket)
- As foot deforms to comply with surface the weight line will become closer to the point of rotation reducing the force needed to be exerted by the amputee





Hypotheses

- A range of stiffness will be observed among prosthetic feet
- A lateral leaning slope will have a more pronounced impact on the stiffness (lateral border of foot will be less stiff)
  - Medial bias of construction of many prosthetic feet
- Multi axis feet will demonstrate less stiffness on non-flat surfaces than other feet types

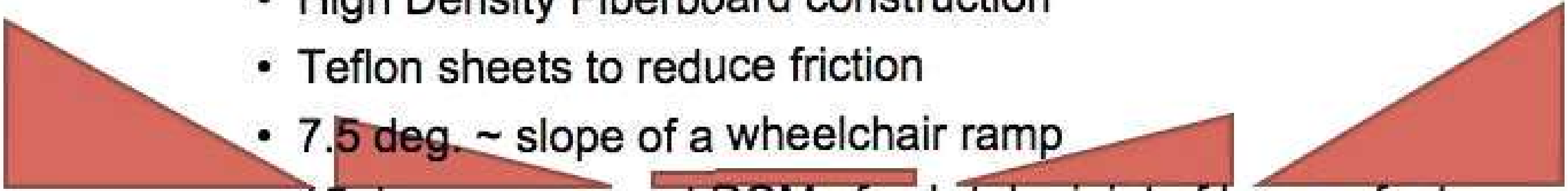
Methods – Foot Selection

- Foot Selection
  - List of available feet
- Foot Specifications
  - Adult, Male
  - 175 lb. (~800 N)
  - Medium Transtibial Amputation
  - Size 27
  - Right foot (if requested)

  - Based on previously used criteria, within range of nearly all feet while still allowing for carrying load of ~25 % body weight.

Methods – Test Set-Up

- Quasi-static cyclic testing
- Servo-hydraulic testing machine (Instron 8521)
- 3 conditions
  - Flat, Medial Slope, Lateral Slope
  - Custom built slope 7.5, 15 degrees
    - (rotated 180 deg. for Medial/Lateral slope)
    - High Density Fiberboard construction
    - Teflon sheets to reduce friction
    - 7.5 deg. ~ slope of a wheelchair ramp
    - 15 deg. ~ near end ROM of sub-talar joint of human foot

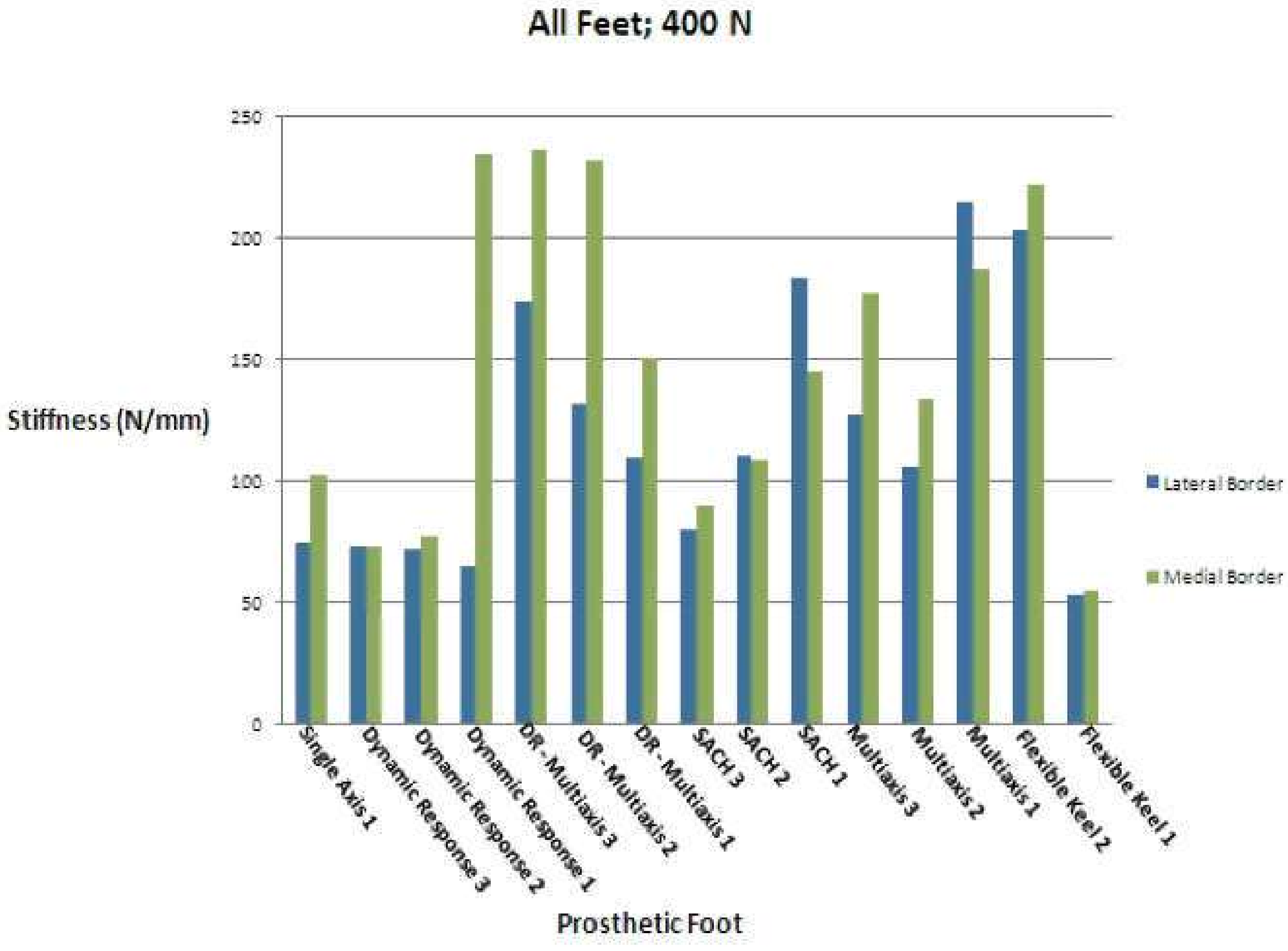


Methods - Testing

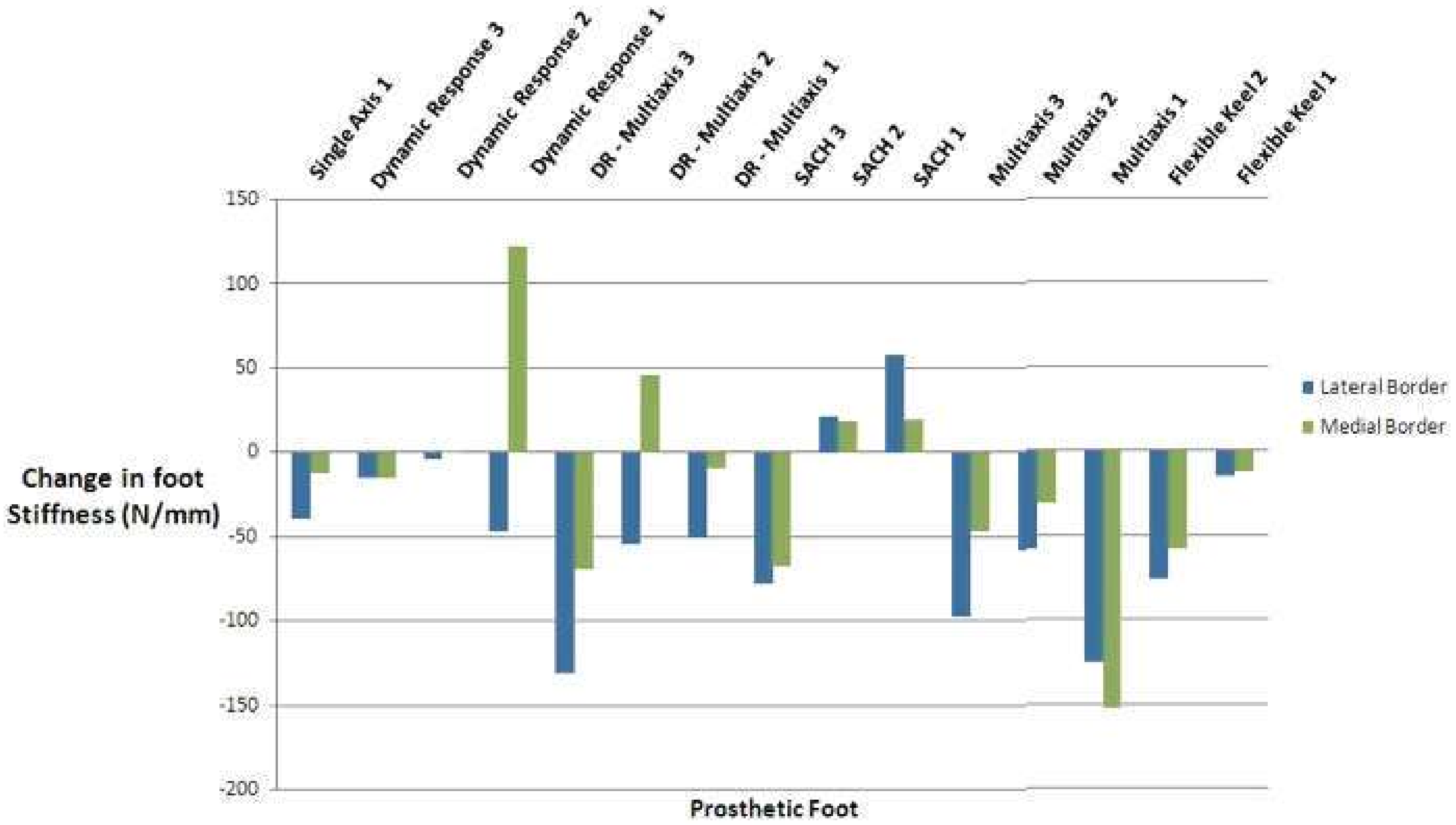
- Feet underwent cyclic loading
  - .25 hz, .75 kN amplitude
- Data recorded at 100 hz
- Data recorded on two separate days for each sample
- 5 trials for each foot, condition
  - Enough to have at least 2 complete cycles

Variability: Day 1 vs. Day 2

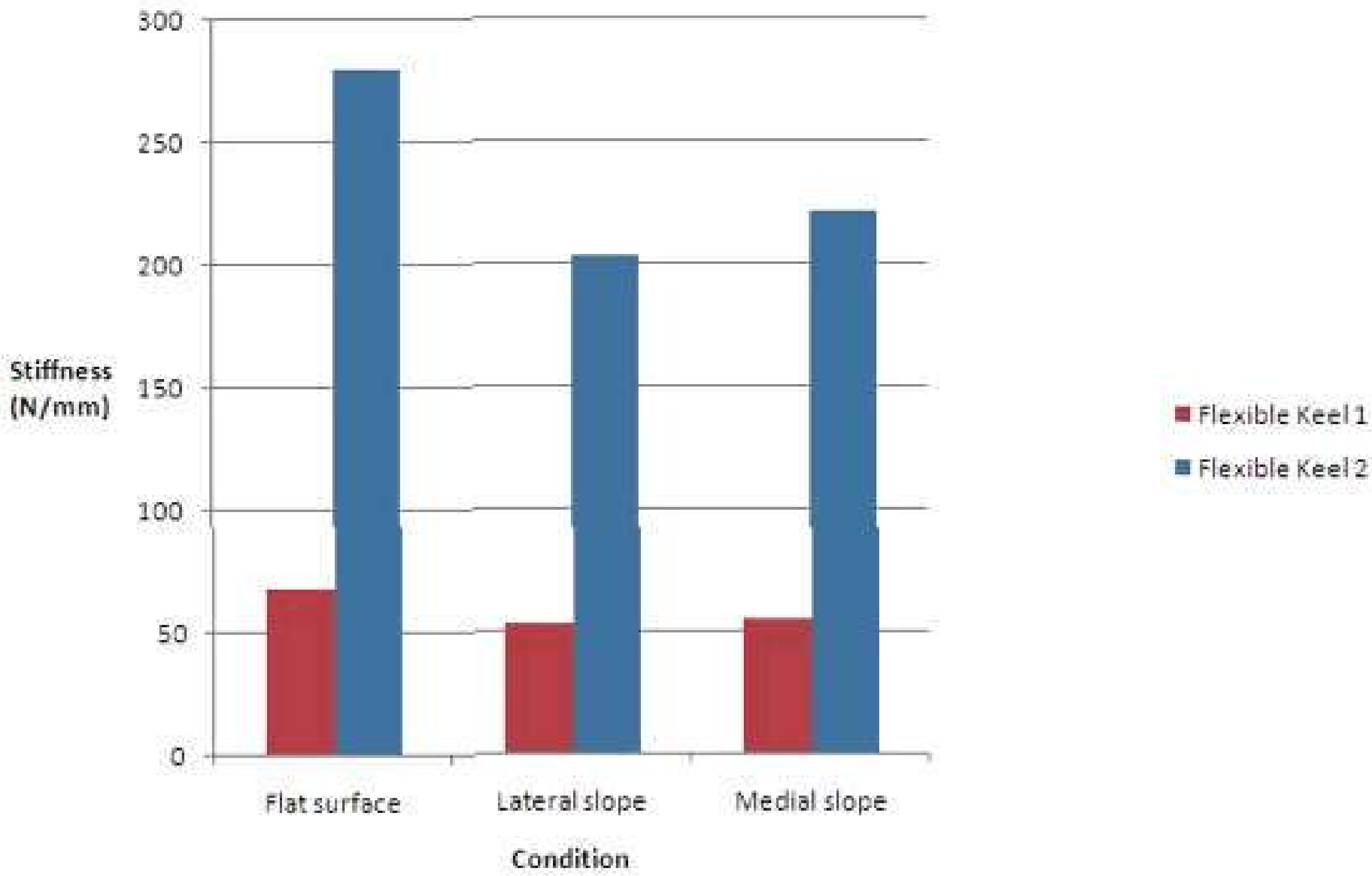
Foot	Correlation	F value	F Critical
Single Axis 1	.99	0.003091	4.113165
Dynamic Response	.96	3.224627	4.300949
Dynamic Response	.99	0.057818	4.300949
Dynamic Response	.96	0.727993	4.259677
DR-Multiaxis 3	.96	3.025917	4.259677
DR-Multiaxis 2	.99	0.576516	4.259677
DR-Multiaxis 1	.99	0.006954	4.225201
SACH 2	.99	1.073648	4.259677
SACH 1	.99	0.069078	4.351243
Multiaxis 3	.99	0.000875	4.351243
Multiaxis 2	.99	0.576516	4.259677
Multiaxis 1	.99	0.201498	4.225201
Flexible Keel 2	.97	0.373659	4.300949
Flexible Keel 1	.97	2.971913	4.195972


All Feet; 400 N
Stiffness (N/mm)
0
50
100
150
200
250
Single Axis 1
Dynamic Response 3
Dynamic Response 2
Dynamic Response 1
DR - Multiaxis 3
DR - Multiaxis 2
DR - Multiaxis 1
SACH 3
SACH 2
SACH 1
Multiaxis 3
Multiaxis 2
Multiaxis 1
Flexible Keel 2
Flexible Keel 1
Prosthetic Foot
Lateral Border
Medial Border

Change in stiffness of foot at 400 N (50% BW)



Flexible Keel Feet; 400 N



Conclusions

- Laboratory tests demonstrate differences between feet.
- Current classification systems do not clearly define foot function.
- Laboratory tests along with clinical evidence can be used for foot prescription reccomendations.

Limitations

- What is clinically acceptable?
- Quasi-static
- Velocity?
- All feet?
- Different phases of gait?

Application

- Primary prosthetic recommendation
  - Initial foot for patient
- Enhanced (secondary) prosthetic recommendation
  - Follow up diagnosis based on patient feedback
- Drive foot manufacture
- Basic understanding of prosthetic foot function

Thank You

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Questions?